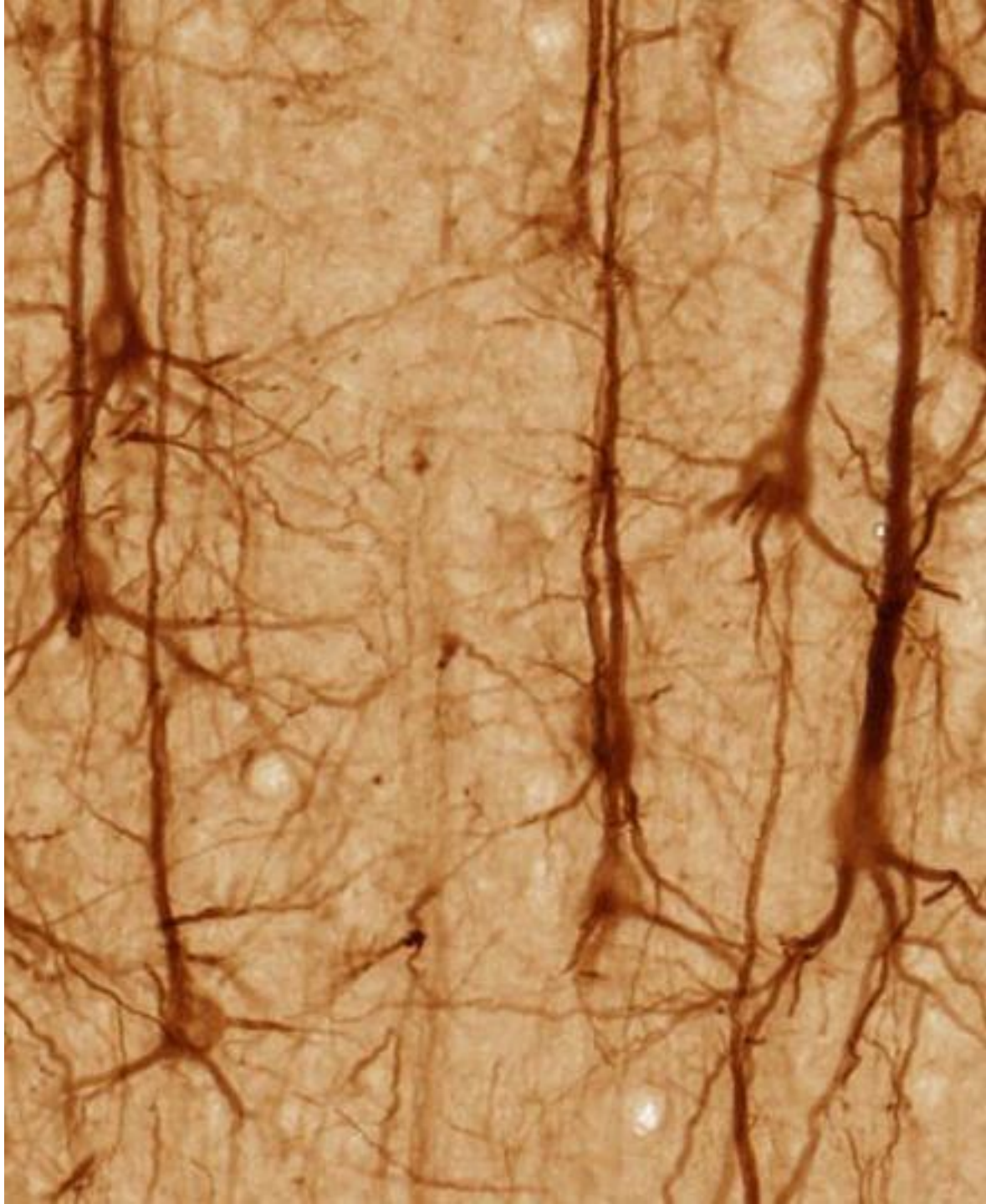
DP Biology – C2.2

Neural signalling

- How do neurons produce electrical signals and pass them along?
- How do neurons affect other cells?

Statements C2.2.1–7, SL and HL. Textbook pp. 467–478.
Image: stained neurons, light micrograph. UC Regents Davis campus, CC BY 3.0.



Objectives for each class

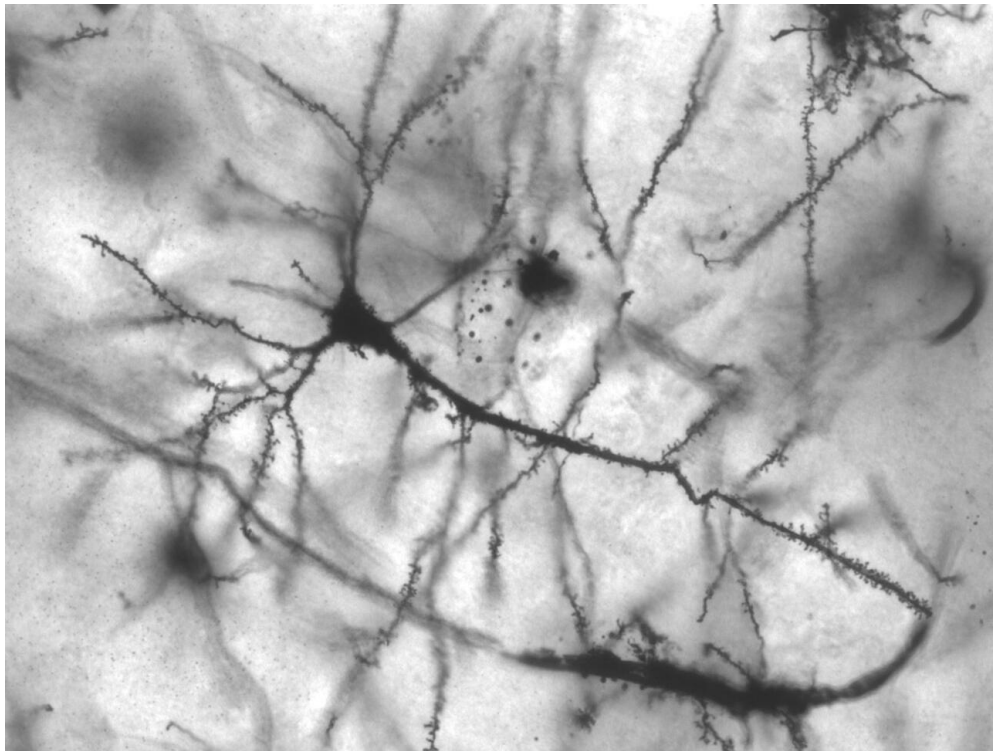
Class	Statements	By the end of the class, you can…
1	C2.2.1–2	Describe the parts of a neuron, and explain how pumping and leakage set up the resting potential
2	C2.2.3	Describe an action potential, and explain why a nerve impulse is electrical
3	C2.2.4	Compare conduction speeds, and explain the effects of axon diameter and myelin
4	C2.2.5–7	Explain how a signal crosses a synapse, using acetylcholine as the example

Overview of this chapter

Part	Statements	What it covers
Neurons	C2.2.1	Cell body, dendrites and axons
At rest	C2.2.2	Pumps, gradients and the resting potential
The impulse	C2.2.3	Action potentials travel along nerve fibres
Speed	C2.2.4	Effects of axon diameter and of myelin
Synapses	C2.2.5	Junctions with other neurons and effector cells
Crossing the gap	C2.2.6–7	Neurotransmitter release and its effect

Neurons carry electrical impulses

- The **central nervous system** (CNS) is the brain and spinal cord
- **Peripheral nerves** link the CNS with all parts of the body
- A **nerve** is a bundle of many nerve fibres
- **Neurons** are the cells that carry impulses
- Signals are fast, and go to particular points in the body



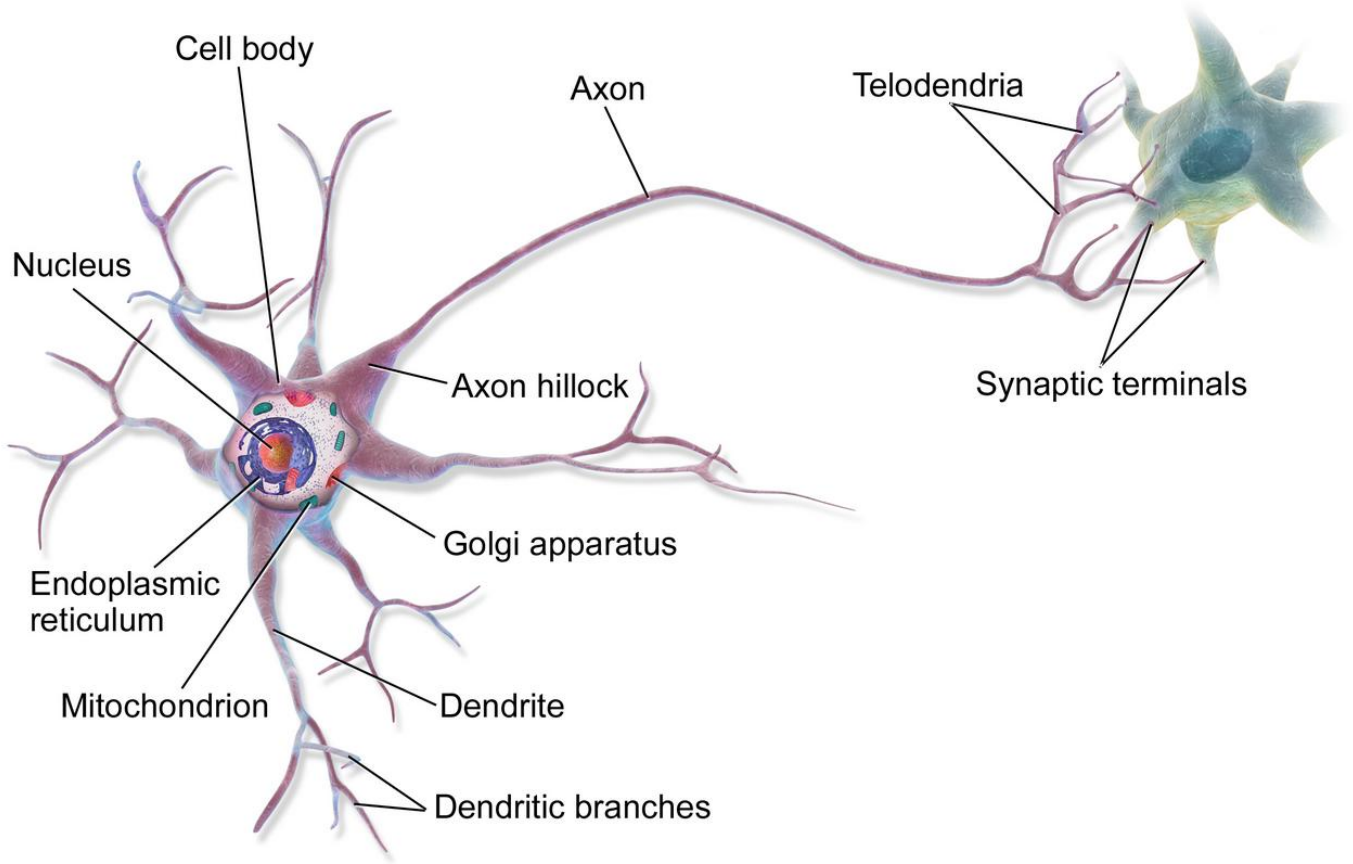
A single neuron from the brain, stained: a cell body with long fibres. MethoxyRoxy, CC BY-SA 2.5.

Link

Hormones also coordinate the body, but they spread in the blood and act more slowly. See C2.1 and C3.1.

The structure of a neuron

C2.2.1



A neuron and its parts. BruceBlaus, CC BY 3.0.

- **Cell body**: cytoplasm and a nucleus
- **Nerve fibres**: elongated, of varying length, projecting from the cell body
- **Dendrites**: multiple short fibres that bring impulses towards the cell body
- **Axon**: one long fibre that carries impulses away

Activity

Draw and label a neuron. Add an arrow to show the direction of the impulse.

Neurons in a pathway

C2.2.1

Neuron	Carries impulses from...	...to
Sensory	Receptors in sense organs	The CNS
Relay	One neuron in the CNS	Another neuron in the CNS
Motor	The CNS	Effectors: muscles and glands

Common mistake

Do not confuse receptors with effectors. Receptors detect stimuli. Effectors respond. Sensory neurons carry the signal from receptors, and motor neurons carry it to effectors.

A resting neuron is polarized



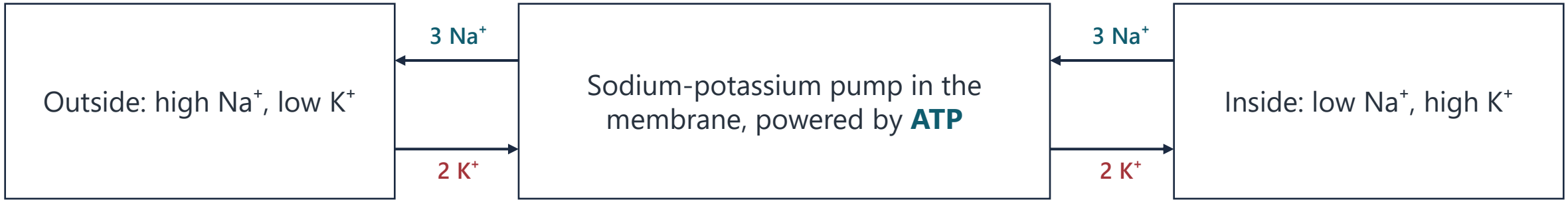
- **Membrane potential**: the difference in charge across a membrane
- **Polarized**: positive on one side and negative on the other
- **Resting potential**: the potential of a neuron not transmitting an impulse, about **−70 mV**
- The negative sign means the inside is negative relative to the outside

Key idea

A resting neuron is not doing nothing. It keeps using ATP to maintain this difference, ready for the next impulse.

The sodium-potassium pump

C2.2.2



- This is **active transport**: ions move against their concentration gradients
- Three Na^+ leave for every two K^+ that enter, so there is a net loss of positive charge
- The pump works in opposite directions and sets up **two concentration gradients**

Key idea

ATP comes from aerobic respiration, so the nervous system needs a steady supply of oxygen and glucose, even when no impulses are passing.

Why the resting potential is negative

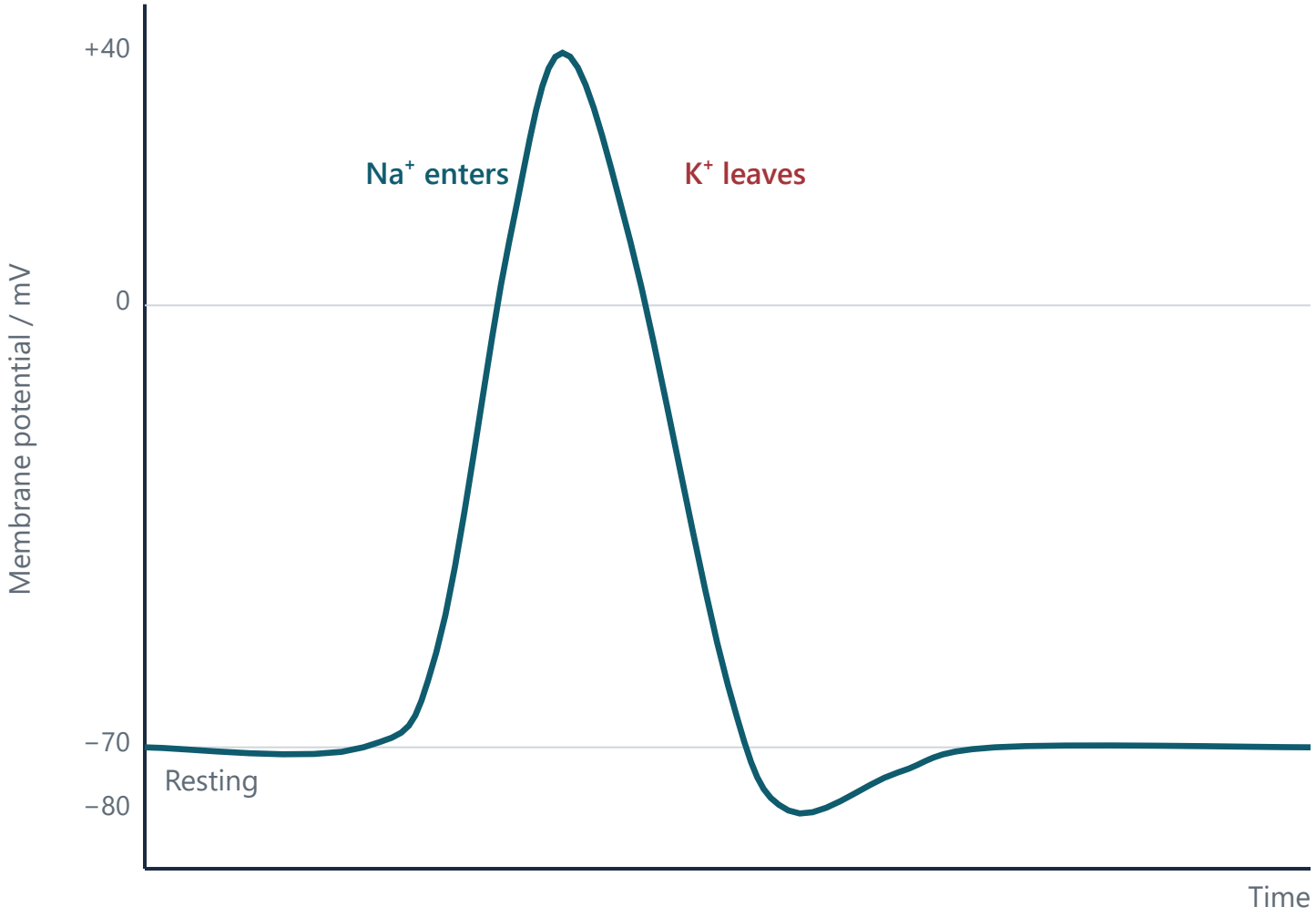
C2.2.2

Contributor	Effect
Sodium-potassium pump	More positive ions are moved out than in
Leakage of ions	K^+ leaks out faster than Na^+ leaks in, as the membrane is more permeable to K^+
Proteins in the cytoplasm	Large, negatively charged proteins stay inside the axon

Exam note

You should be able to explain the energy source (ATP), what polarization and membrane potential mean, and why the value is negative. A useful figure to remember is about −70 mV, including its sign.

An action potential



Schematic, not to scale. One point on the axon. The whole event lasts a few milliseconds.

- A stimulus causes Na^+ to enter the axon
- The potential reverses, from about −70 mV to about **+40 mV**: **depolarization**
- K^+ then leaves, restoring a negative potential: **repolarization**
- This is the **action potential**

Exam note

More detail on channels and thresholds is in the HL statements C2.2.8–10.

Impulses travel along nerve fibres

C2.2.3

- A nerve impulse is an action potential **propagated** along a fibre
- It is **electrical** because it involves the movement of positively charged ions, changing the voltage
- It is not like a current in a wire: charged ions move across the membrane, one region after the next
- Each point on the fibre is depolarized for only about two thousandths of a second
- The next region is then triggered, so the impulse moves along

Question

A neuron is sometimes described as being like an electric cable. Give one way in which this comparison helps and one way in which it misleads.

Wider fibres conduct faster

C2.2.4



Squid (Loligo). Its giant axons trigger a rapid escape response. Hans Hillewaert, CC BY-SA 4.0.

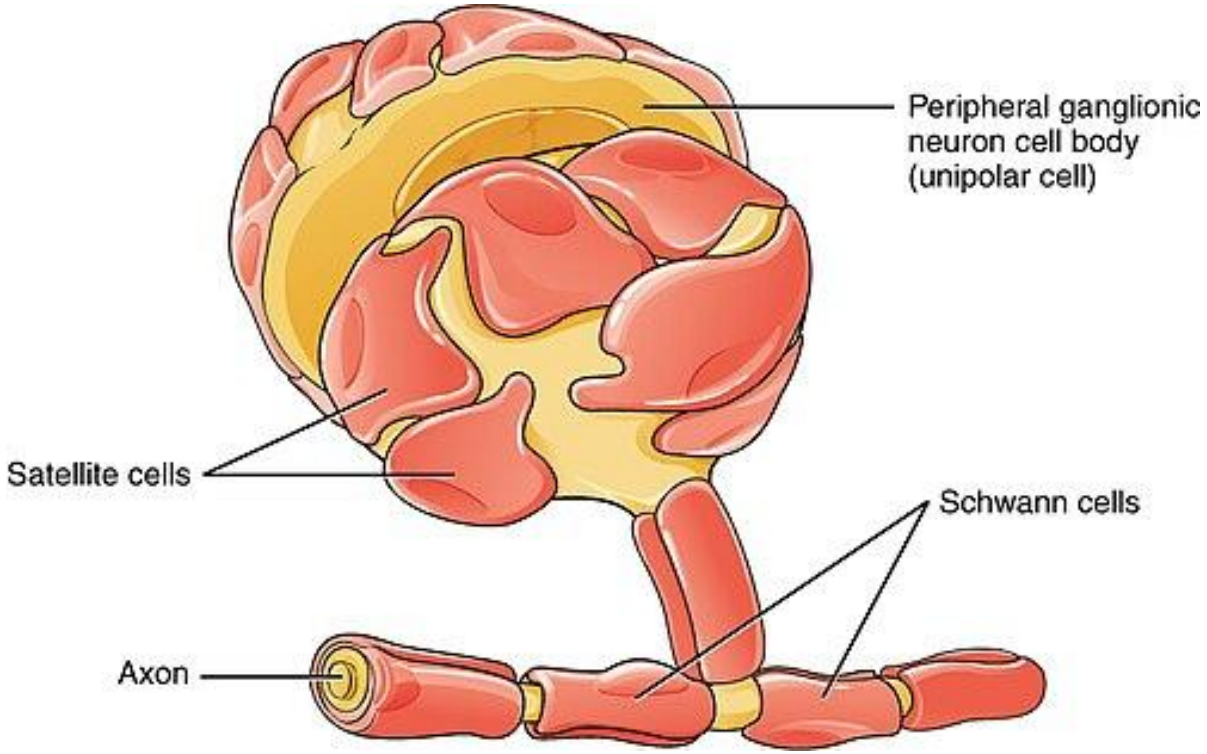
- Small non-myelinated fibres, about 1 µm wide: about 1 m per second
- Squid giant axons, up to 500 µm wide: about 25 m per second
- A narrow fibre gives more **resistance** to the flow of ions
- Giant axons made early measurements of nerve impulses possible

Question

Suggest how a giant axon helps a squid to survive. Why would it be impossible for humans to have giant axons in all of their many nerve fibres?

Myelin greatly increases speed

C2.2.4



Schwann cells wrap around axons in the peripheral nervous system. OpenStax, CC BY 4.0.

- **Schwann cells** wrap around the axon, forming a **myelin sheath**
- Myelin is rich in lipid and has a high electrical resistance
- Gaps in the sheath are **nodes of Ranvier**
- The membrane is exposed only at the nodes, so the impulse jumps between them
- Myelinated fibres can reach about 100 m per second

Link

HL students study this jumping in more detail, as saltatory conduction (C2.2.11).

Comparing conduction speeds

C2.2.4

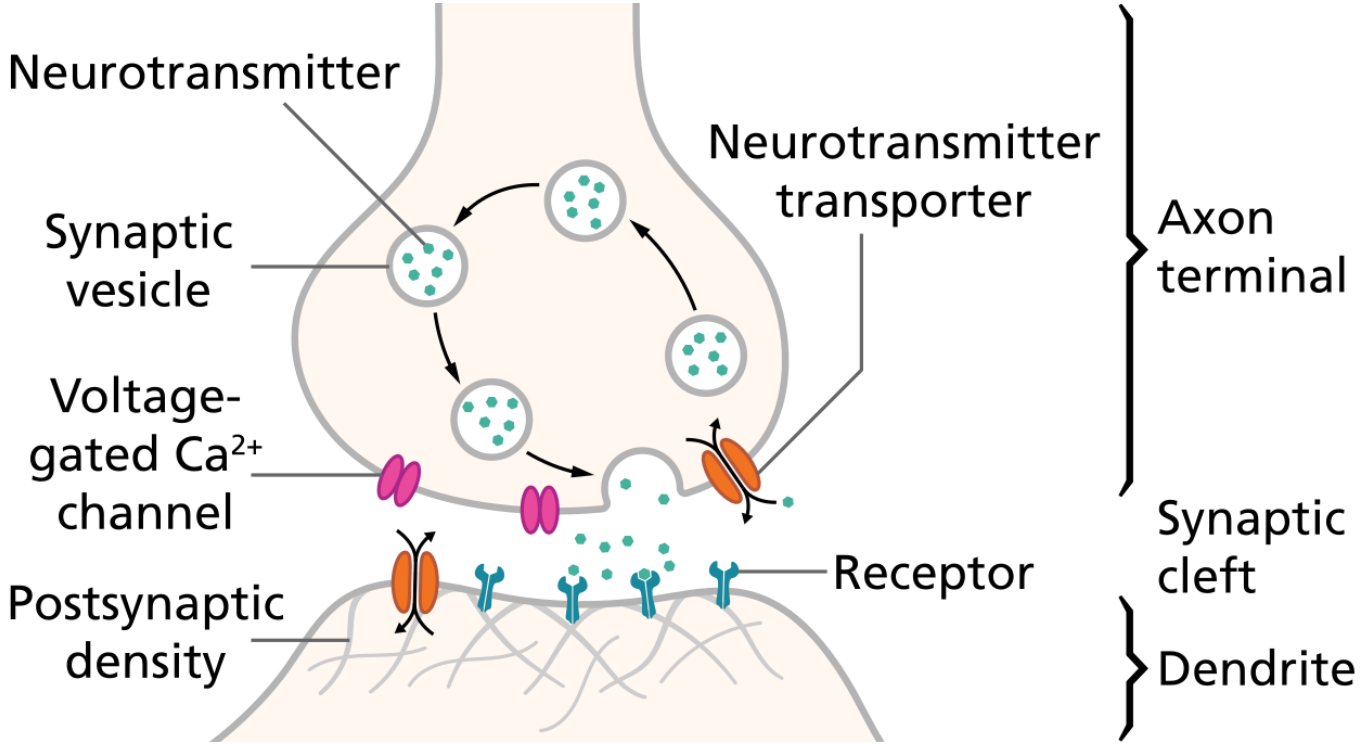
Fibre	Diameter	Myelinated?	Typical speed
Small fibre in a mammal	1 µm	No	About 1 m/s
Squid giant axon	500 µm	No	About 25 m/s
Mammal motor fibre	20 µm	Yes	About 100 m/s

Activity

Use the Monash University simulation: ilearn.med.monash.edu.au/physiology/action-potentials/axon-diameter
Run it with non-myelinated fibres. What is the effect of diameter on speed? Repeat with myelinated fibres. Plot both data sets, add trend lines, and suggest why myelin gives little benefit in very small axons.

Synapses are junctions

C2.2.5



A chemical synapse. Thomas Splettstoesser, CC BY-SA 4.0.

- The **presynaptic neuron** ends in a swollen knob
- The **postsynaptic** cell receives the signal
- A **synaptic cleft**, about 20 nm wide, separates them
- An action potential cannot cross the cleft

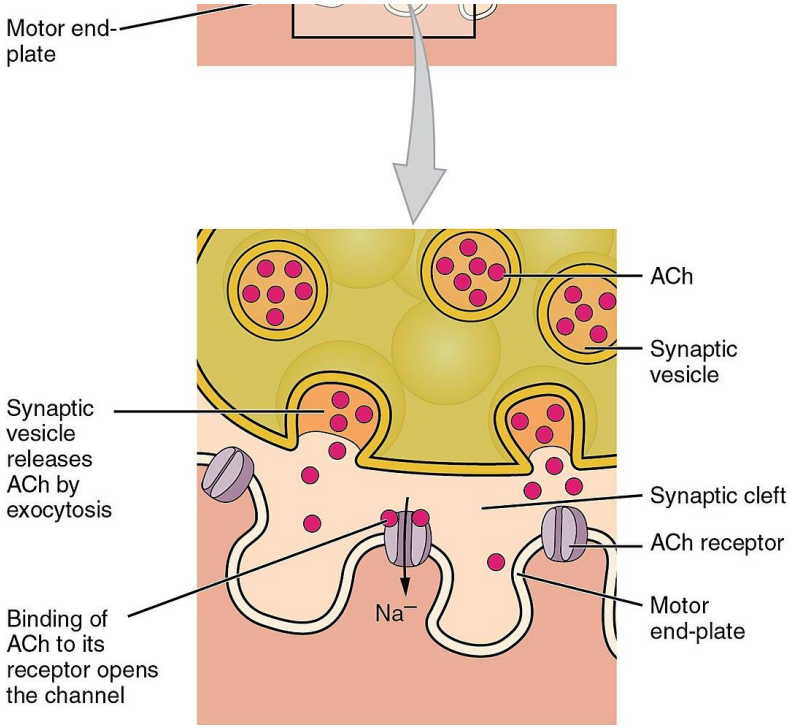
Key idea

Neurotransmitters carry the signal across. They are made in the knob and stored in vesicles.

Where synapses are found

C2.2.5

Junction	Example
Neuron to neuron	Throughout the brain and spinal cord
Neuron to muscle	Neuromuscular junction
Neuron to gland	Secretion from a salivary gland



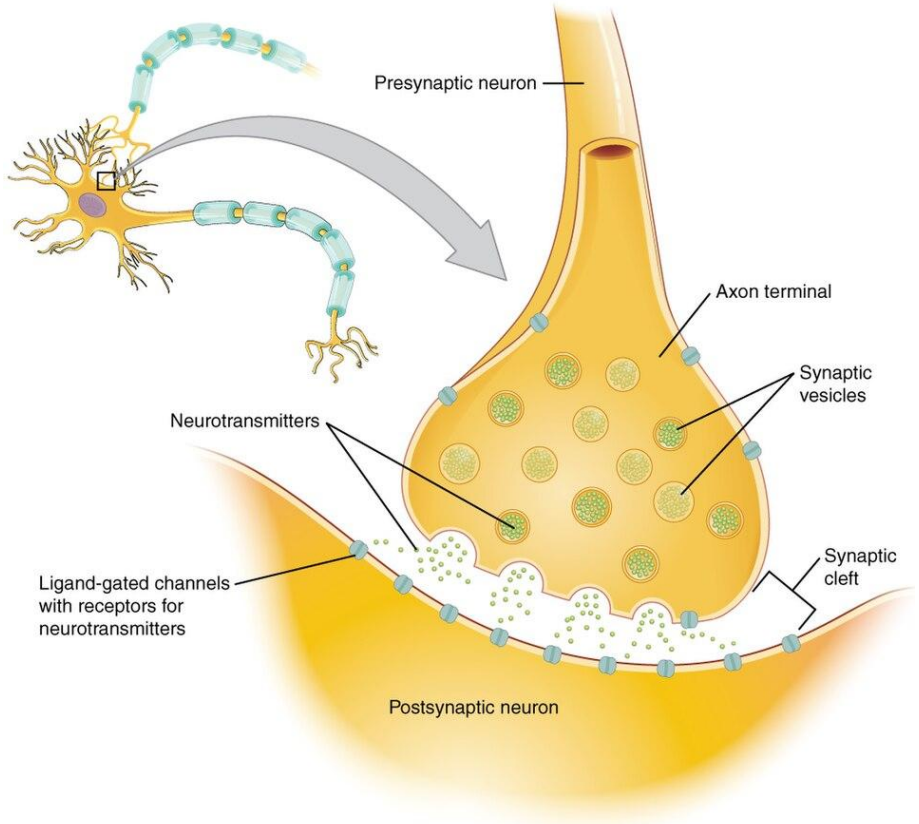
Neuromuscular junction: a motor neuron ending on a muscle fibre. OpenStax, CC BY 4.0.

Why one direction?

A signal can cross a typical synapse in only one direction. Vesicles of neurotransmitter occur only in the presynaptic neuron, and receptors for it occur only on the postsynaptic membrane.

Releasing the neurotransmitter

1. An action potential reaches the synaptic knob and depolarizes the **presynaptic membrane**
2. Calcium channels open, and **Ca^{2+}** diffuses in from the cleft
3. Calcium acts as a **signal inside the neuron**, making vesicles move to the membrane
4. Vesicles fuse with the membrane, releasing neurotransmitter into the cleft



Events at a chemical synapse. Young et al., OpenStax, CC BY 4.0.

Key idea

Electrical signal in, chemical signal across, and then electrical signal again in the next cell.

An excitatory postsynaptic potential

C2.2.7

1. **Acetylcholine (ACh)** diffuses across the cleft, from high to low concentration
2. It binds to a specific **transmembrane receptor** on the postsynaptic membrane
3. The receptor is also an ion channel, and it opens
4. **Na^+** enters the postsynaptic cell, down its gradient, and the membrane depolarizes
5. This change is an **excitatory postsynaptic potential**. If it is large enough, an action potential begins

Common mistake

Do not write that the neurotransmitter 'moves' across the cleft. It reaches the membrane by diffusion, from high to low concentration.

Exam note

Use acetylcholine as your example. It is found in many types of synapse, including the neuromuscular junction, where it triggers muscle contraction.

Clearing the cleft

C2.2.7

1. Neurotransmitter must be removed, or the postsynaptic cell would remain stimulated
2. The enzyme **acetylcholinesterase** breaks ACh down to choline and acetate
3. The ion channel closes and the resting potential is restored
4. Choline is reabsorbed by the presynaptic knob, and ACh is made again using ATP

Activity

Write the whole sequence as a numbered flow chart, from an action potential arriving to acetylcholine being remade. Then cover it and redraw it from memory. Finally, explain why a synapse has many mitochondria.

Check that you can explain

1. The parts of a neuron
2. How the pump establishes gradients
3. Why the resting potential is negative
4. What happens in an action potential
5. Why an impulse is electrical
6. How diameter and myelin affect speed
7. What a synapse is
8. Why a synapse works in one direction
9. What calcium ions do
10. How acetylcholine causes a postsynaptic potential

Exit activity: 5 minutes

On your own and without notes. Hand this in as you leave.

1. Give two reasons why the inside of a resting axon is negative.

2. Put in order: (A) Na^+ enters the next cell. (B) Ca^{2+} enters the knob. (C) Acetylcholine diffuses across the cleft. (D) Vesicles fuse with the membrane. (E) Acetylcholine binds to receptors.

3. Explain why a signal can cross a typical synapse in only one direction.

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